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Anthropogenic trigger of substorms and energetic particles precipitations

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Abstract

The high-frequency (HF) emission in near-Earth space from various powerful transmitters (radio communications, radars, broadcasting, universal time and navigation stations, etc.) form an integral part of the modern world that it cannot do without. In particular, special-purpose research facilities equipped with powerful HF transmitters are used successfully for plasma experiments and local modification of the ionosphere. In this work, we are using the results of a complex space-ground experiment to show that exposure of the subauroral region to HF emission can not only cause local changes in the ionosphere, but can also trigger processes in the magnetosphere–ionosphere system that result in intensive substorm activity (precipitations of high-energy particles, aurorae, significant variations in the ionospheric parameters and, as a consequence, in radio propagation conditions).
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1. Introduction

The ionosphere (its state) is a substantial component of space weather as a medium important to the radio propagation forecast. By "space weather" we usually understand variations in the Sun, solar wind, magnetosphere, and ionosphere that can affect the operation and stability of spaceborne and ground-based technological systems, as well as the human health and life. It is shown that, along with the main factors responsible for the state and dynamics of the ionosphere (the Sun and solar activity, magnetospheric processes, etc.), an essential effect is caused "from below" (meteorological events, seismic activity, volcanoes, explosions, rocket launches, tsunami, shore effect) (Danilov et al., 1987; Deminov et al., 2001; Gokhberg and Shalimov, 2004; Afraimovich and Perevalova 2006; Zalizovsky and Yampolsky, 2007; Molchanov and Hayakawa, 2008; Devi et al., 2010).

The priority task of space research nowadays, particularly as concerns the space weather forecast, is a detailed study of near-Earth space and its variability factors, as well as the possibility to control the parameters of the medium in order to reduce economical risks. A number of present-day research programs, e.g. HAARP (Alaska, USA) (http://www.haarp), are aimed at broad investigations in this field. In Russia, we have a single facility ("Sura") (Belikovich et al., 2007) for stimulation of the ionosphere by high-power radio emission designed in the past century, whose capacity is an order lower than the capacity of the up-to-date US facility or the European Tromso facility. The experiments carried out with the use of the EISCAT radar (Northern Norway) demonstrated the possibility of triggering local substorm activity as a result of modification of the ionosphere/magnetosphere interactions by controlled injection of powerful radio waves to the nighttime auroral ionosphere (Blagoveshchenskaya et al., 2000). Note that EISCAT is located at auroral latitudes where the level of various geomagnetic and plasma disturbances is usually high, which determines the particularities of heating experiments in that region. Modification of the

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ionosphere by amplitude-modulated powerful radio waves and injection of low-frequency waves into the Earth magnetosphere is a priority line of experiments with the HAARP heating facility. HAARP has the highest energy potential (effective emission power up to 36 GW) and the lowest emission frequency compared to the other heaters, which ensure the generation of more intensive plasma disturbances. Even a brief review of the results listed above reveals a great interest the scientific community takes in the opportunities associated with modification of the Earth ionosphere and magnetosphere by high-power radio emission from the ground-based heating facilities.

Here, we present the results of our new experiments (Kuznetsov et al., 2008) carried out with the use of the Sura HF transmitters. These results show that the ground-based service systems that employ powerful HF transmitters may, under certain conditions, trigger a substorm – an energetic phenomenon in the magnetosphere–ionosphere circuit, which results in high-energy particle precipitations, auroral glows, and noticeable variations in the ionospheric parameters. The experiments were supported by measurements at ground-based observatories and on board the International Space Station (ISS), GPS system, and Demeter satellite. It should be noted that magnetic disturbances that could be interpreted as substorms triggered by the heater operation were only recorded in two of all the ionospheric heating experiments carried out within the Sura-ISS program during 2007–2012.

2. Description of the first experiment (02.10.2010) of the Sura-ISS program

The Russian mid-latitude heating facility – Sura (56.13N, 46.1E) makes it possible to carry out ionospheric plasma experiments outside the highly dynamic auroral zone. In recent years, a series of new experiments has been carried out on its basis invoking other ground-based and space-borne facilities, in particular, the Russian segment of the International Space Station (ISS). The novelty of the Sura-ISS program consisted in the search for resonance conditions for triggering powerful natural processes by a relatively weak though purposeful action. One of such natural phenomena in near-Earth space is the substorm activity. The experiments were conducted under nighttime conditions. The ionosphere was irradiated by the ordinarily polarized radio emission, as a rule, at the frequency of 4.3 MHz. The peculiarity (Karabadzhak et al., 2009; Ruzhin et al., 2009) was that, in all experiments, the critical frequency *foF2* of the ionospheric F2-layer was always lower than the working frequency of the heating wave (heating "by transmission"), and the powerful radio emission covered the entire column of the ionosphere within the antenna diagram. The modulation frequency was close to the frequency of natural Alfven oscillations of plasma in the magnetic flux tube resting on the heated spot in the ionosphere. The geometry of the experiments in geographical coordinates is represented in Fig. 1. The dotted lines show

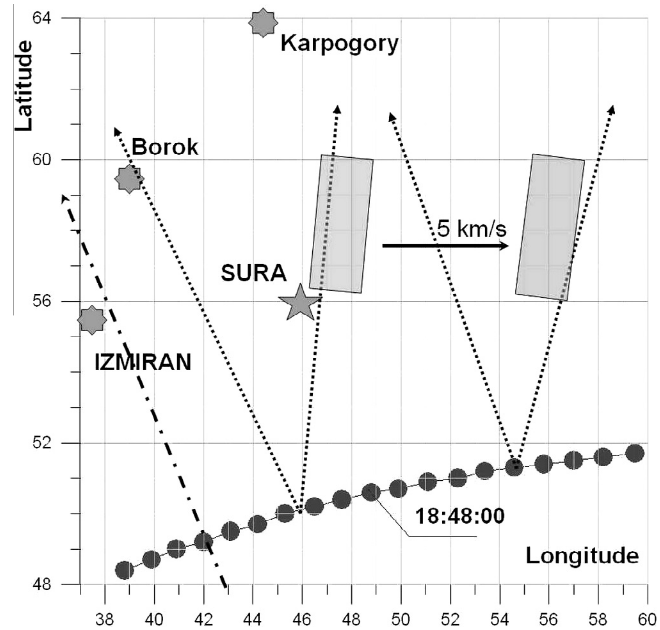

Fig. 1. The scheme of observation of optical phenomena on board the RS ISS during the heating experiments. The circles represent the projection of the ISS orbit, the dotted lines show the recorder field of view, and the dash-dotted line is the orbit of the Demeter satellite.

the field of view of the ISS optical instruments directed horizontally towards the Sura facility (northwards). More than 12 experiments were carried out following this scheme during the period of the Sura-ISS program (2007–2012). The table below gives the main parameters of the heating radio wave (HW) and the ionospheric characteristics for two measurement sessions, in which the substorm-type geomagnetic disturbances were recorded.

3. ISS optical measurements

All experiments (Fig. 1) were supported by observations on board the ISS Russian segment. An advantage of the ISS optical observations, in particular, observations with the use of the "Fialka" spectrozonal system (Karabadzhak et al., 2009) is the possibility of two-dimensional imaging of processes in the vicinity of the heating region with a recording camera with the horizontally oriented axis (limb measurements). The use of the ISS equipment for optical observations of the heated spot increases the brightness of the artificial glow owing to a convenient geometry – a flat layer in the image plane is observed from the butt end. Under such conditions, the brightness of the glow recorded in the heating region must increase tenfold.

In the experiment of 2 October 2007, the Sura facility was operating in the periodic heating mode from 18:40 to 19:00 UT (one minute heating, one minute pause). The minimum emission power was 10 MW. The axis was inclined by 12° southward. Fig. 1 shows the projection of the ISS trajectory onto the Earth (trace) and the position

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